91602
new 82-10

ontario hydro
research division

STRESS EFFECTS ON DEFORMATION MODULUS AND DILATOMETER SENSITIVITY

Report No 86-351-K

R. Koopmans & R.W. Hughes
Rock Sciences Section
Civil Research Department

ABSTRACT

This report investigates the effect of various stress levels on the determination of deformation moduli and examines the sensitivity of the borehole dilatometer in measuring rock mass scale features. Results indicate that the deformation modulus of a rock mass can be substantially affected by the stress field and that the dilatometer is sensitive enough to profile deformation moduli as dictated by rock mass characteristics.

job	file	date	report no.
44-163-502	841.2412	February 17, 1987	86-351-K

TABLE OF CONTENTS

		Page
1.0	INTRODUCTION	1
2.0	BACKGROUND	1
3.0	EQUIPMENT AND TESTING PROCEDURE	2
4.0	STRESS EFFECT ON DEFORMATION MODULUS	2
	4.1 Testing of Rock Blocks	2
5.0	DILATOMETER INFLUENCE ZONE	3
	5.1 Concrete Cylinder Analysis	3
6.0	DISCUSSION	3
	6.1 Stress Effects on Deformation Modulus	3
	6.2 Dilatometer Influence Zone	5
7.0	CONCLUSION	5
REFERENCES		7
FIGURE 1	Setup for Three Directional Loading of Rock Blocks	8
FIGURE 2	Setup Showing Dilatometer Insertion in Rock Block	9
FIGURE 3	Schematic Showing Location of Dilatometer and Strain Gauges	10
FIGURE 4	Granite Rock Block - Stress vs Deformation Moduli	11
FIGURE 5	Limestone Rock Block - Stress vs Deformation Moduli	12
FIGURE 6	Sandstone Rock Block - Stress vs Deformation Moduli	13
FIGURE 7	URL Access Shaft - BH-S3 - Deformation Moduli vs Depth	14
FIGURE 8	Deformation Modulus with Depth from Donkin Tunnels 2 and 3	15

TABLE OF CONTENTS (Cont'd)

		Page
FIGURE 9	Donkin Mines - Tunnel 3 - In Situ Stresses with Depth	16
FIGURE 10	Upper Quadrant of Pressurized Dilatometer Showing Stress Contours with Radial Distance from Centre of Borehole in Concrete Cylinder	17
FIGURE 11	Upper Quadrant of Pressurized Dilatometer Showing Stress Contours with Radial Distance from Centre of Borehole in Finite Element Analysis of Influence Zone	18
TABLE I	Deformation Modulus with Increasing Stress for Rock Blocks	19
DISTRIBUTION		- last page -

ontario hydro
research division

To Mr. H.N. Isaac
Manager, Nuclear Materials
Design and Development Division

Attn: Mr. T.J. Carter

STRESS EFFECTS ON DEFORMATION MODULUS AND DILATOMETER SENSITIVITY

1.0 INTRODUCTION

This report is part of an investigation to determine techniques to assess the effects of excavation within a rock mass surrounding an underground radioactive-waste repository. Although the borehole dilatometer has already been shown to be a useful device in characterizing rock mass properties (Koopmans and Hughes (1985a) and Koopmans and Hughes (1985b)), some questions relating to its sensitivity and zone of influence still remained to be addressed. This work package studies the effect of various stress levels on the determination of deformation moduli and examines the sensitivity of the borehole dilatometer in measuring rock mass scale features and its ability to represent rock mass characteristics. Cubical blocks of sandstone, limestone and granite were tested under triaxial stress conditions to assess deformation moduli with changing stress. The dilatometer's zone of influence was determined by conducting tests within an instrumented concrete cylinder and by performing a finite element analysis.

2.0 BACKGROUND

Several authors, for example Boughton (1968), Howarth (1984) and Patrick et al (1985) indicate that the stress field influences the deformation moduli obtained during load testing in rock. This was also noted by the present authors in previous modulus testing projects conducted in various rock types (Koopmans, 1983; Koopmans and Hughes, 1985a). It is reasonable to assume that an increase in stress would result in a more compact rock mass of higher stiffness due to the closure of microcracks and discontinuities. On the contrary, the opposite effect would be encountered at lower stress levels.

It has been reported that borehole devices, such as dilatometers, are relatively insensitive to rock mass scale features and provide results less characteristic of the true rock mass modulus because of the small volume of rock influenced in each measurement (Schrauf and Pratt, 1979). On the contrary, Heuze (1980) suggests that borehole devices such as the NX borehole

jack influences the rock mass some seven borehole diameters from the loading plate. This represents a rock mass volume which is more than 500 times greater than that of a standard NX core sample.

3.0 EQUIPMENT AND TESTING PROCEDURE

The testing programs were undertaken with the aid of a computerized borehole dilatometer system. Details concerning this equipment are provided elsewhere (Koopmans and Hughes, 1984) and will, therefore, not be repeated here. Prior to testing, the dilatometer is calibrated in both an aluminum and steel thick-walled cylinder. Five cycles are run for each calibration after which the dilatometer is placed in an EX (3.81 cm diameter) borehole in rock or concrete. Once again, five cycles are run. Due to the very small volume changes which occur within the dilatometer, especially in high modulus rock, more accuracy is obtained by averaging the slopes of the curves together. Pressures in the order of 2 MPa are used to seat the dilatometer, while pressures of 7 to 25 MPa are used at the top of each cycle. The lower values (7 to 18 MPa) are used in testing rock blocks in order to prevent them from failing in tension especially under low confining pressures. Upon completion of testing, calibrations are taken once more to verify the original calibrations. With the aid of a computer, both pressure and volume are recorded every second and stored on floppy disk. At the same time, the points are both plotted and printed out to enable immediate analysis, if desired. The slope of the straight line portion of the curve is determined by using the least squares method for each of the runs and averaging them together with the aid of a computer. Another computer program is then used to determine the deformation modulus.

4.0 STRESS EFFECT ON DEFORMATION MODULUS

4.1 Testing of Rock Blocks

EX boreholes were drilled through the centres of cubical (30.5 cm diameter) blocks of sandstone, limestone and granite. The various rock types were tested using the computerized borehole dilatometer system under changing stress levels. Triaxial stresses were administered to each rock block with the aid of three hydraulic jacks and a load frame. The deformation modulus was determined for confining stress fields increasing from 0.7 to 9 MPa. A constant pressure of 2.8 MPa was maintained in the third direction to simulate an overburden pressure. The load frame used was rectangular in shape, thereby allowing the rock block to be placed in one corner while two loading jacks were placed inside of the load frame to apply loads horizontally and vertically (Figure 1). To enable loading in the third direction, two I-beams were placed on each side of the load frame and fastened together with the aid of steel threaded bars and support

plates. One of the steel bearing plates contained a central hole to allow the borehole dilatometer to be inserted in between the two I-beams, through the plate and into the block specimen (Figure 2). The loads were applied using three hydraulic hand pumps. The deformation modulus was determined for increasing triaxial loads. This procedure was carried out for granite, sandstone and limestone rock blocks.

5.0 DILATOMETER INFLUENCE ZONE

5.1 Concrete Cylinder Analysis

In an effort to determine the volume of influence affected by a dilatometer in a rock mass, an instrumented concrete cylinder was prepared. The dimensions of the cylinder were approximately 0.91m in diameter and 0.91m in height (Figure 3). Early high strength concrete was poured into a 0.91m diameter Sonotube to half height. Eight concrete strain gauges were placed horizontally in the concrete prior to filling to full height.

These gauges were placed at increasing distances from the axis of the cylinder so that the radial influence of the dilatometer could be measured. After the concrete had cured to a compressive strength or approximately 34.5 MPa, an EX borehole was drilled through the centre of the cylinder. Testing commenced by placing the centre of the dilatometer in the borehole at the elevation of the instrumented plane. Subsequent to load testing to 14 MPa and recording the strain readings from all gauges, the dilatometer was moved to different locations along its length to simulate its zone of influence at various heights. The stresses were calculated using a deformation modulus of 20.7 GPa as determined from borehole modulus tests using the dilatometer. The zones of influence for each tested plane were then plotted on one graph in order to determine the overall volume of influence. In a similar fashion to Heuze (1979), the 2 per cent stress level was selected as the boundary limit in the determination of the rock mass volume of influence. For an applied pressure of 14 MPa, the cutoff point at the two per cent contour would therefore be 0.28 MPa.

A finite element program was run to determine the zone of influence for comparative purposes. In this model, internal pressures of approximately 20 MPa were applied to the wall of a borehole having a diameter of 3.81 cm. A modulus of 20.7 GPa was assumed for this study.

6.0 DISCUSSION

6.1 Stress Effects on Deformation Modulus

The deformation modulus with increasing levels of confining pressure for sandstone, limestone and granite based on laboratory

testing, is shown in Figures 4,5 and 6 and tabulated in Table 1. It can be observed that changes in the level of the confining stresses can substantially alter the deformation modulus of the rock. With increasing stress, there is a tendency for the deformation modulus to level out. This is most likely due to the closure of microfractures which are open when the rock block is in a relaxed state. Based on these results, one could expect low in situ deformation moduli for rock masses which are influenced by low stress magnitudes and higher deformation moduli for higher stressed zones.

The laboratory simulations on rock blocks support the in situ field test results carried out previously by the authors. Figure 7 shows an example of deformation moduli distribution with radial depth from the access shaft wall of the Underground Research Laboratory (URL) in Manitoba (Koopmans and Hughes, 1985a). Testing was conducted in four EX (3.81 cm diameter) boreholes to depths of approximately 15 metres. The first five metres were tested at 0.25 metre intervals, while the next 10 metres were tested at one metre intervals. It would appear that stress relaxation has occurred as a result of shaft excavation. Figure 7 indicates that lower moduli are obtained close to the excavation where in situ stresses are lower and increase to a point approximately 4 metres deep, where the values level out. It is assumed that the stress field is relatively constant and not affected by the excavation at distances greater than 4 metres.

The profile of deformation moduli with depth in the sandstone rock mass between two parallel tunnels in the Donkin Mine, Nova Scotia is shown in Figure 8. (Koopmans and Hughes, 1985b and Canmet, 1985). One tunnel was excavated using a tunnel boring machine (TBM) while the second tunnel was mined using drill and blast techniques. Tests were carried out from within each tunnel at 0.25 metre intervals to a depth of 5 metres and at 0.5 metre intervals at depths in excess of 5 metres. Results indicate that high moduli are encountered in the rock mass close to the TBM excavation, while lower moduli are obtained in the rock mass close to the drill and blast excavation (Figure 8). In the TBM excavation, reasonably constant values averaging 9.92 GPa are found at a depth greater than about 6 metres. In the drill and blast excavation, moduli gradually increase over the depth of approximately 6 metres after which they increase quickly before dropping off to 9.92 GPa. Since the moduli also levelled out at an average of 9.92 GPa with depth from the TBM excavation, it is assumed that this value is constant between the two tunnels, once approximately one tunnel diameter is exceeded.

Based on a limited number of USBM and CSIRO stress measurements taken in the drill and blast tunnel (Canmet, 1985), it is noted that lower radial and tangential stresses are obtained to a depth of approximately one tunnel diameter (7 to 8 metres) after which

the stresses increase rapidly and level out with increasing depth (Figure 9). Hammer seismic surveys conducted in both tunnels provide lower dynamic moduli (12 to 30 GPa) in the drill and blast tunnel and higher dynamic moduli (23 to 34 GPa) in the TBM tunnel (Canmet, 1985).

The results obtained from both laboratory and field tests indicate that deformation moduli can be significantly influenced by the in situ stress field. This investigation also suggests that low tangential moduli are obtained in the rock mass surrounding excavations mined using less cautious procedures due to stress relaxation. On the contrary, carefully mined and supported tunnels can have higher tangential moduli where higher compressive stresses prevail.

6.2 Dilatometer Influence Zone

The results of determining the zone of influence of the EX dilatometer in a concrete cylinder is shown in Figure 10. The figure shows the stress contours for the upper right quadrant of a pressurized dilatometer. The 2% stress contour extends to a radial distance of approximately 16cm or about four borehole diameters. The volume of the ellipsoid representing this zone is equal to 10.6 cubic decimetres. For comparative purposes, this influences a volume in excess of 40 times that of a standard NX core sample.

The zone of influence, as determined by the finite element model prepared to simulate dilatometer loading in an EX borehole, is shown in Figure 1. This analysis also shows a zone of influence of approximately 4 times the borehole diameter based on the 2 per cent stress level. The investigation suggests that the borehole dilatometer influences a zone which is considered to be significant enough to represent the actual rock mass characteristics. The fact that deformation moduli obtained using a borehole dilatometer are influenced by the in situ stress field and rock mass features such as discontinuities is conclusive evidence to support this statement. It should also be emphasized that models, which represent a rock mass influenced by an excavation, should reflect changes in moduli from the excavation wall to a point at depth where the rock mass is no longer affected by excavation disturbance.

CONCLUSION

The results of both laboratory and in situ field programs indicate that deformation moduli can be substantially affected by the in situ stress field. This investigation also suggests that the borehole dilatometer is capable of representing rock mass scale features, which can be profiled by conducting tests at relatively close intervals. With the aid of the computerized borehole dilatometer system, deformation moduli in low to high

modulus rock can be rapidly and economically determined. Information obtained in this manner allows one to determine the extent of excavation disturbance, locate fractures and establish a realistic model to simulate the near field rock mass behaviour.

Approved by:

T.W. Klym
Manager
Civil Research Dept

Submitted by:

R. Koopmans
Geotechnical Engineer
Rock Sciences Section

Submitted by:

R.W. Hughes
Geotechnical Technician
Rock Sciences Section

Reviewed by:

A.T. Jakubick
A/Supervising Engineer
Rock Sciences Section

RK:EJ

REFERENCES

Boughton, N.O., 1968, "Correlation of Measured Foundation Modulus with the In-Situ Rock Properties", Proceedings of the International Symposium on Rock Mechanics, Madrid, pp 303-306.

Canmet Contract Report No 265Q.23440-2-9159, 1985. "Measurement and Analysis of Rock Deformation and Support System Response in the Drill and Blast and Bored Access Drivages at the Donkin-Morien Project (UP-G198) - Golder Associates", Vol 2.

Heuze, F.E., 1979, "Scale Effects in the Determination of Rock Mass Strength and Deformability", Rock Mechanics, Vol 12, pp 167-192.

Howarth, D.F., 1984, "Apparatus to Determine Static and Dynamic Elastic Moduli", Rock Mechanics and Rock Engineering, Vol 17, pp 255-264.

Koopmans, R., 1983, "Bedrock Degradation as Determined from Plate Bearing Tests", International Symposium on Soil and Rock Investigations by In-Situ Testing, Vol 2, Paris, pp 77-81.

Koopmans, R. and Hughes, R.W. 1984, "An Automated and Computerized Dilatometer System to Measure Deformation Modulus of Rock", Western States Mining Expo-84, Reno, Nevada.

Koopmans, R. and Hughes, R.W., 1985a, "Determination of Near Field Excavation Disturbance in Crystalline Rock", 9th International Symposium on the Scientific Basis for Nuclear Waste Management, Stockholm.

Koopmans, R. and Hughes, R.W., 1985b, "The Determination of In Situ Deformation Modulus - Donkin Mines - Nova Scotia", Ontario Hydro Research Division Report No 85-72-H.

Patrick, W.C., Yow, J.L., Jr and Axelrod, M.C., 1985, "Observations of Borehole Deformation Modulus Values Before and After Extensive Heating of a Granitic Rock Mass", Proceedings 26th U.S. Symposium on Rock Mechanics, Rapid City, SD, pp 851-858.

Schrauf, T.W. and Pratt, H.R., 1979, "Review of Current Capabilities for the Measurement of Stress, Displacement and In Situ Deformation Modulus", ONWI-95, Distribution Category UC-70.

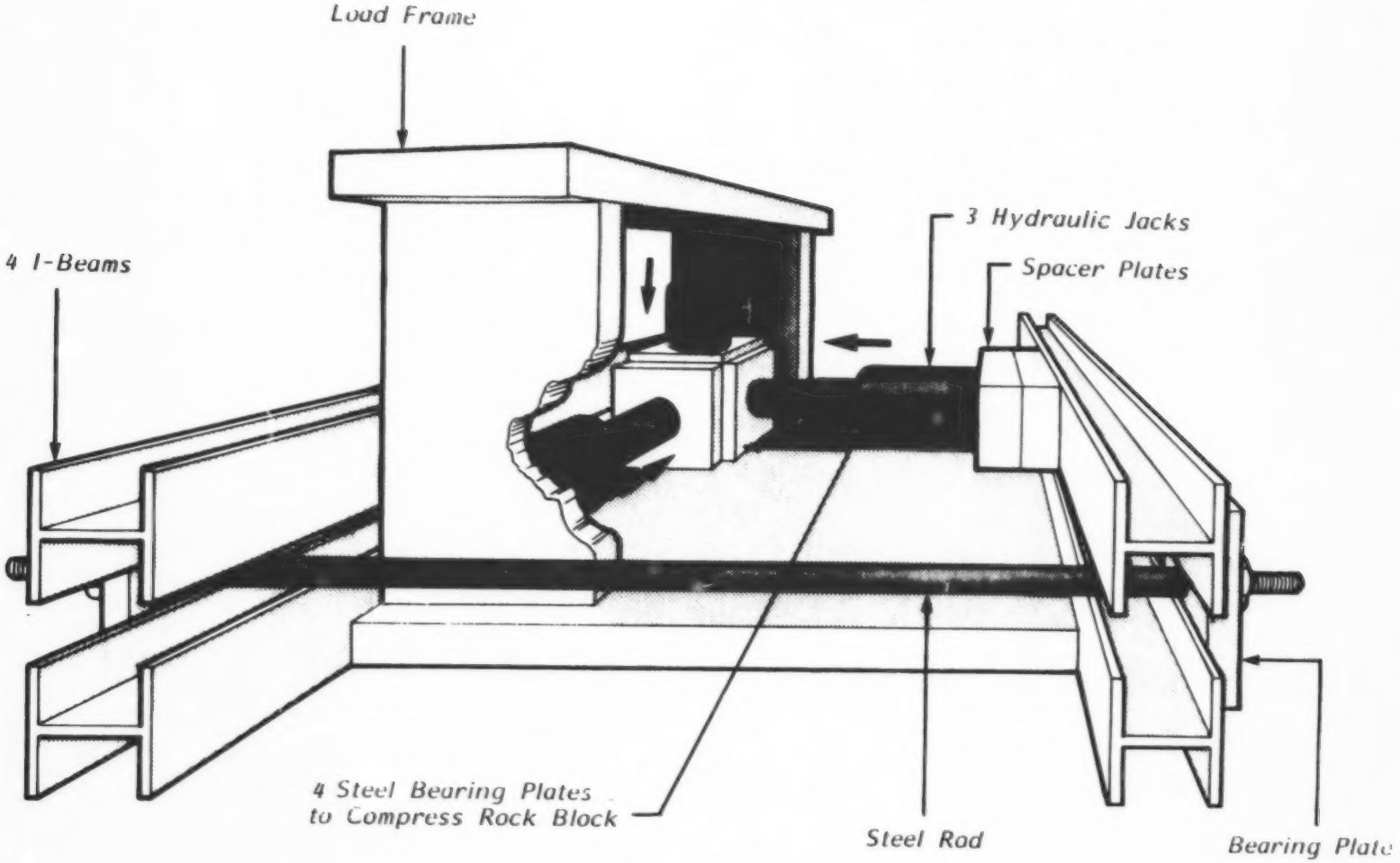


FIGURE 1
SETUP FOR THREE DIRECTIONAL LOADING OF ROCK BLOCKS

173157-RD

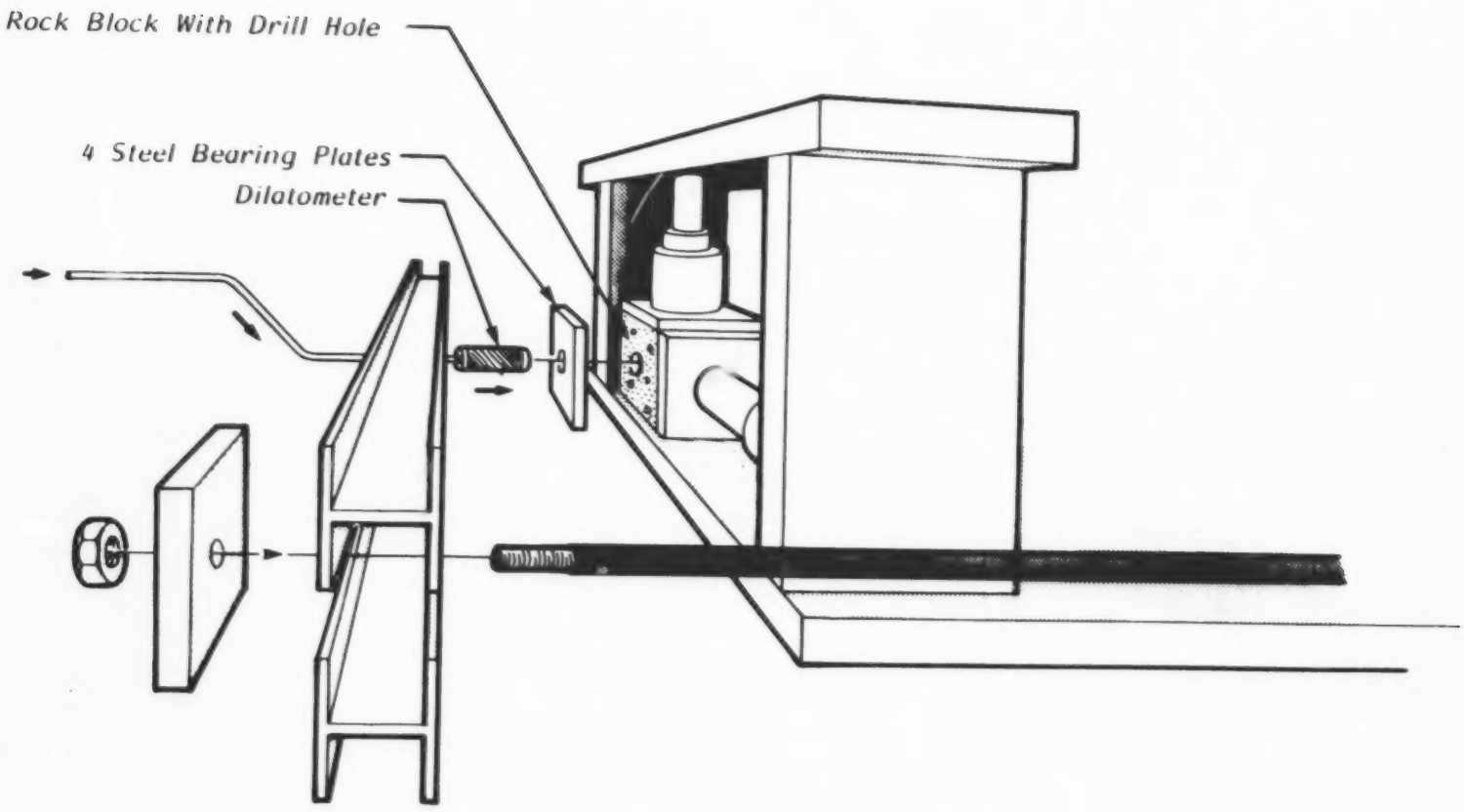
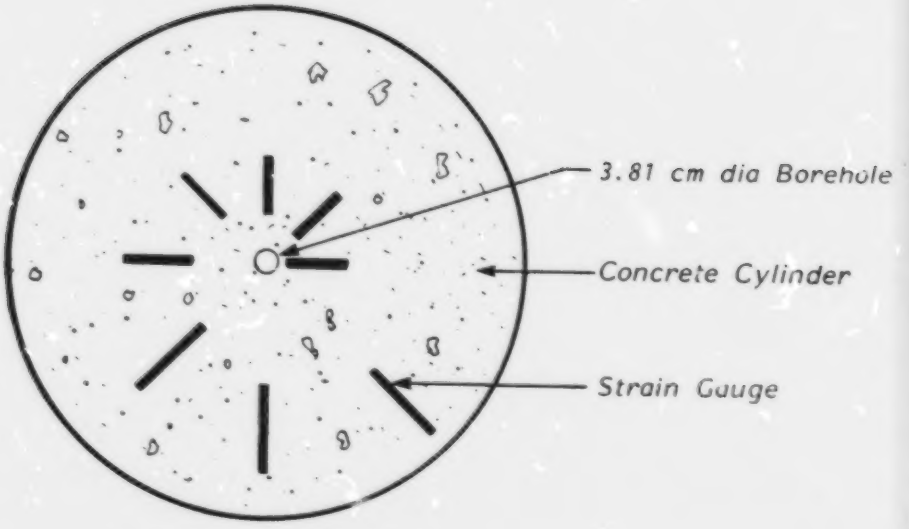
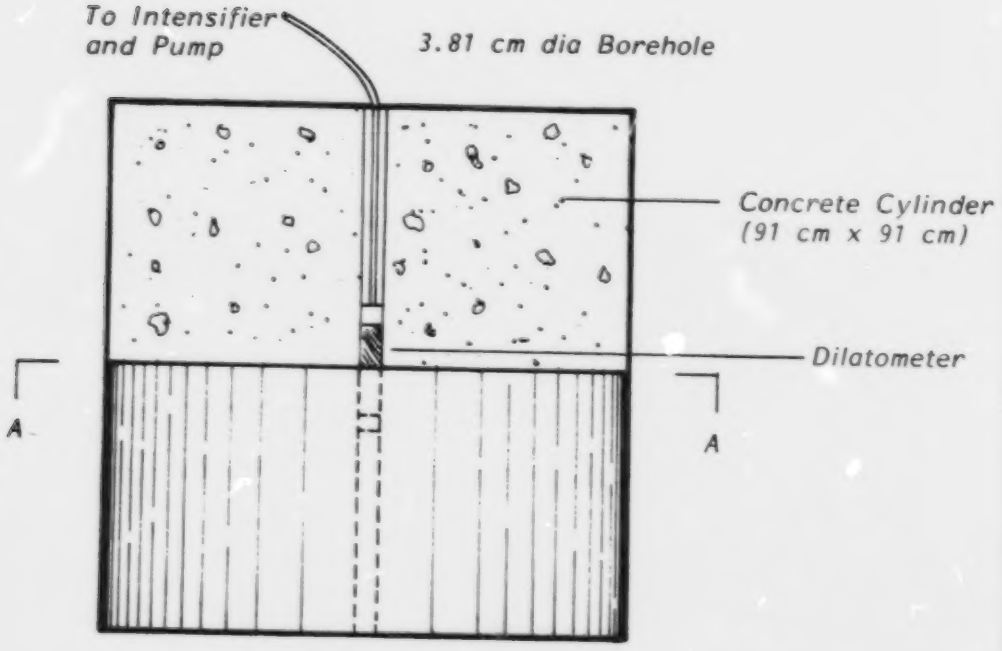


FIGURE 2
SETUP SHOWING DILATOMETER INSERTION INTO ROCK BLOCK

173158-RD



PLAN VIEW OF SECTION AA



ELEVATION VIEW OF CONCRETE CYLINDER

FIGURE 3

SCHEMATIC SHOWING LOCATION OF DILATOMETER AND STRAIN GAUGES

173159-RD

FIGURE 4 — GRANITE ROCK BLOCK

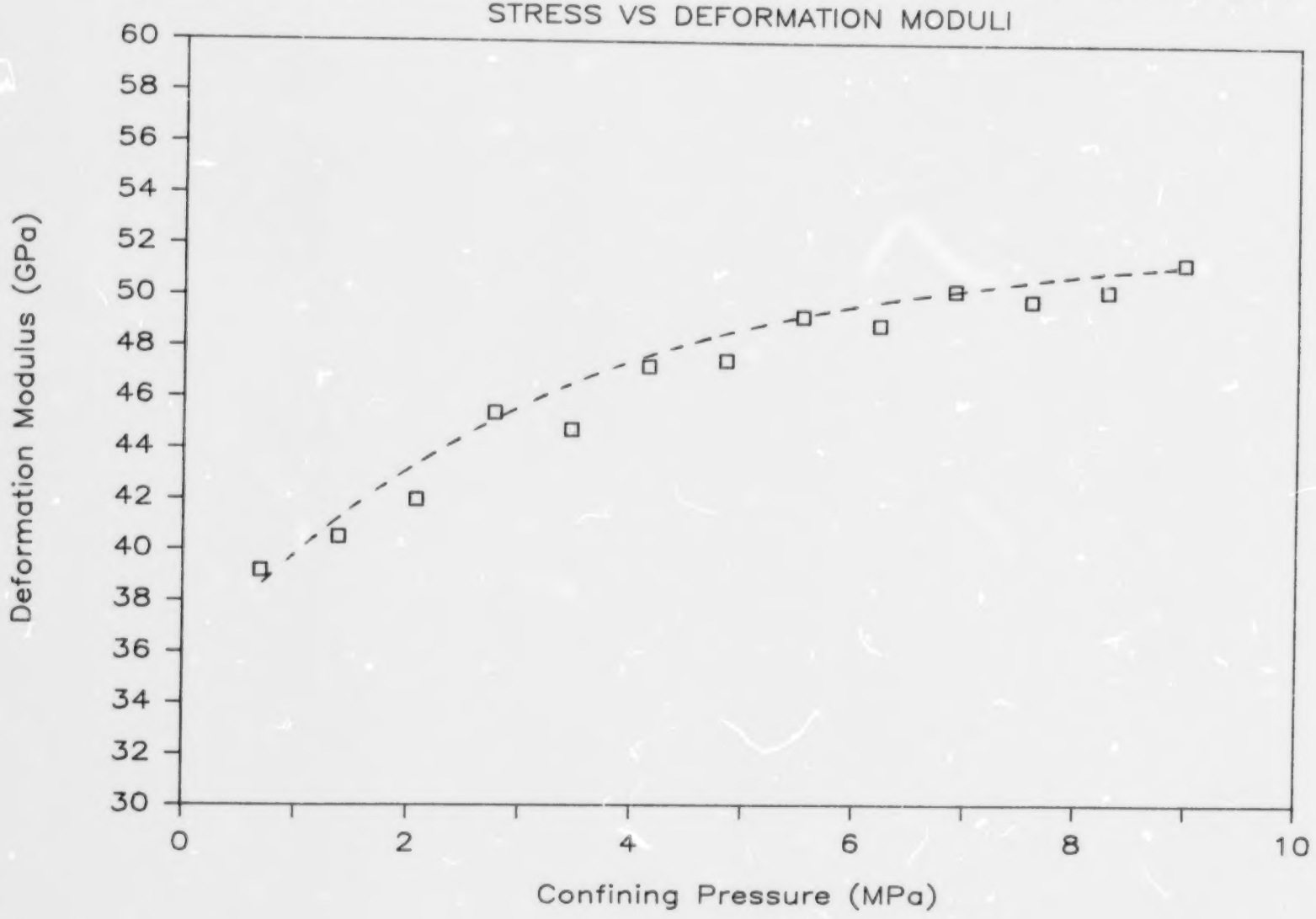


FIGURE 5 — LIMESTONE ROCK BLOCK

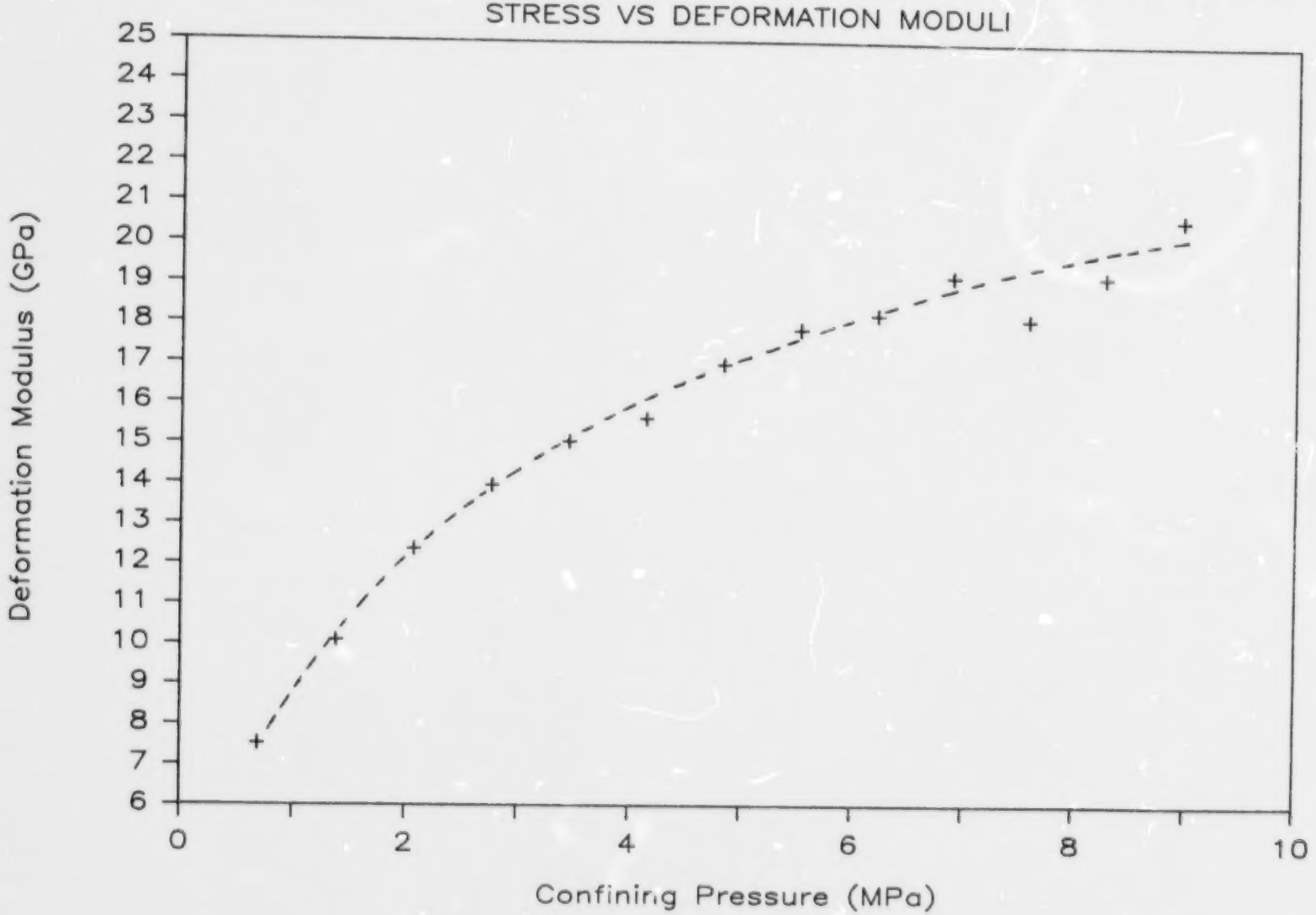


FIGURE 6 – SANDSTONE ROCK BLOCK

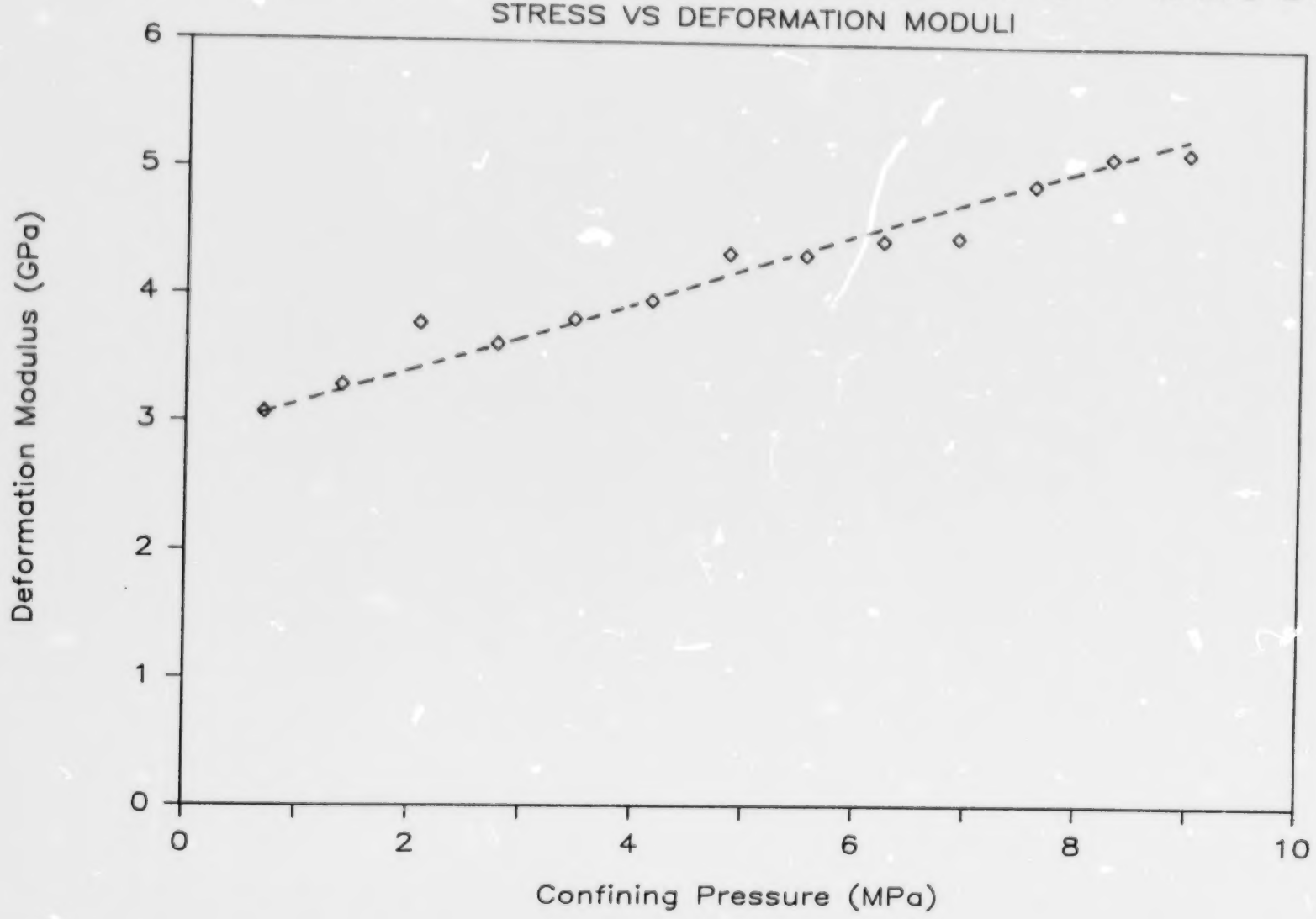
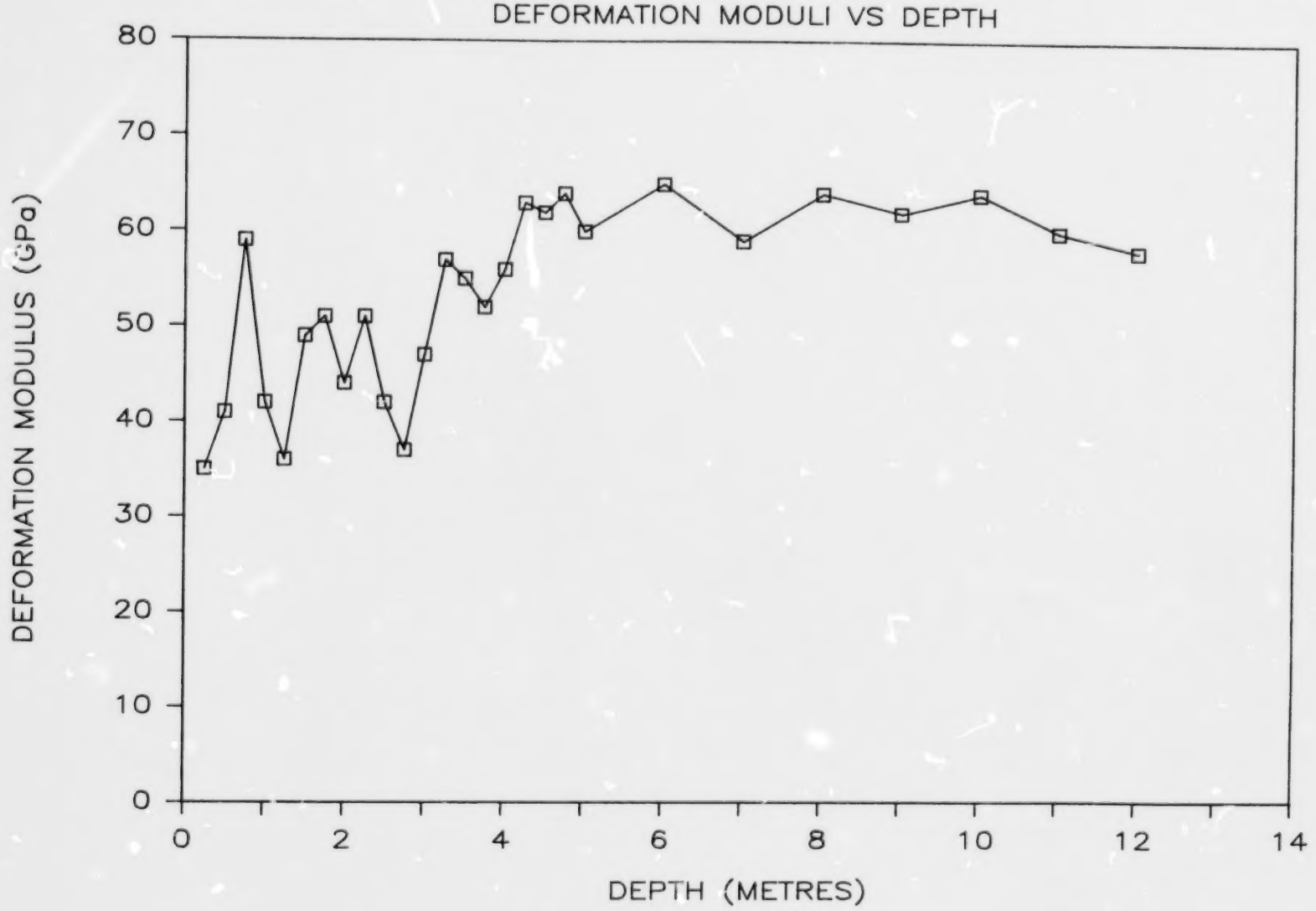


FIGURE 7 – URL ACCESS SHAFT – S3



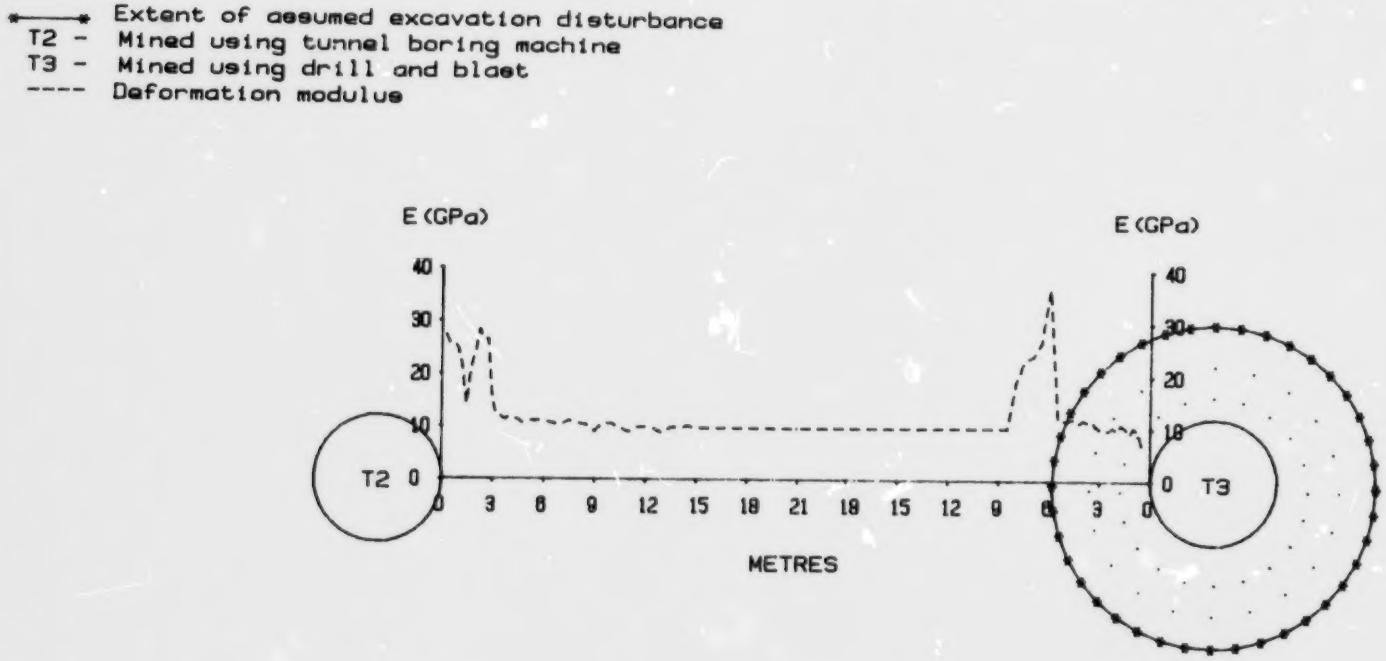
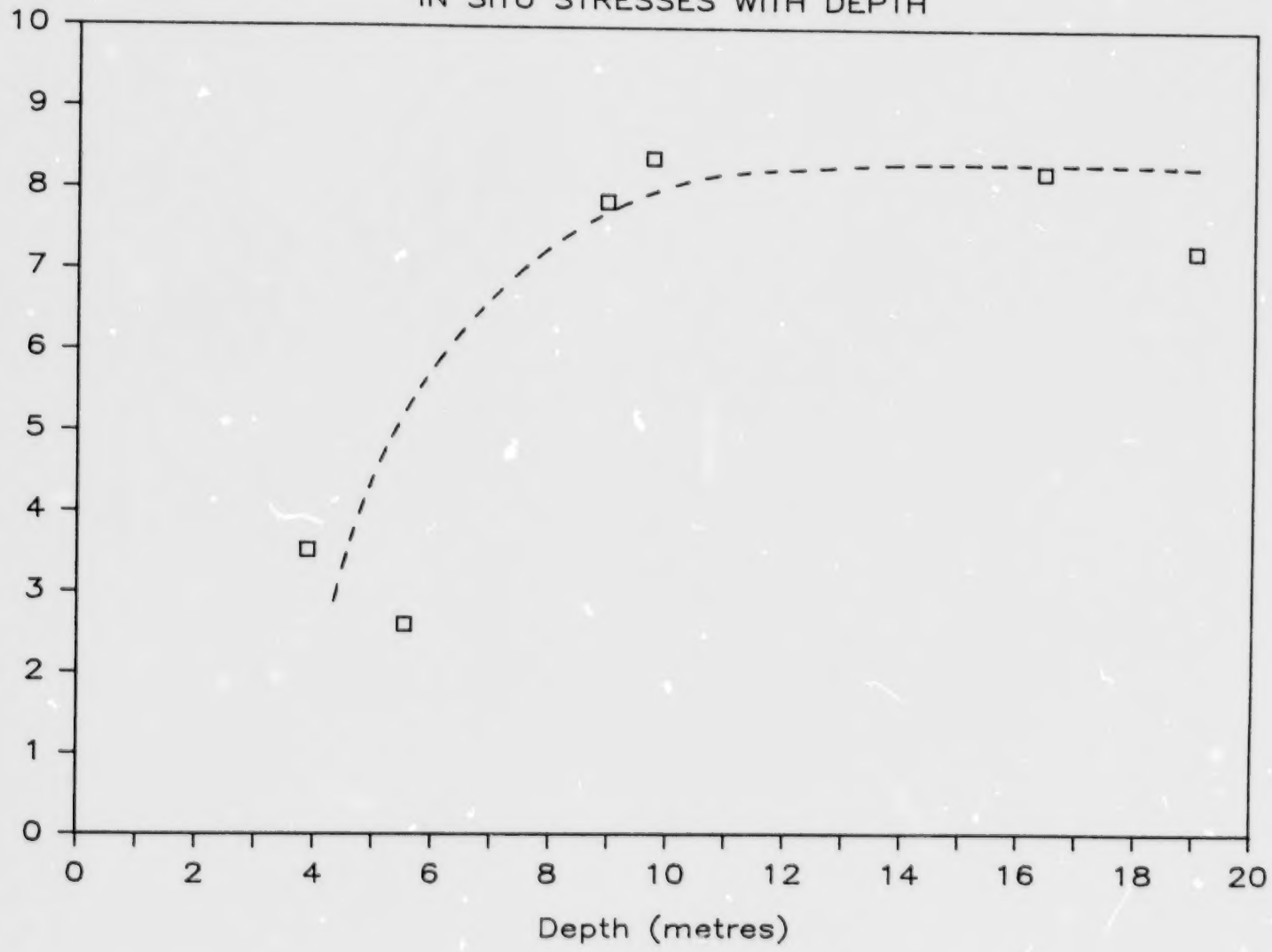


FIGURE 8

DEFORMATION MODULUS WITH DEPTH
FROM DONKIN TUNNELS 2 AND 3

FIGURE 9 — DONKIN MINES — TUNNEL 3

IN SITU STRESSES WITH DEPTH



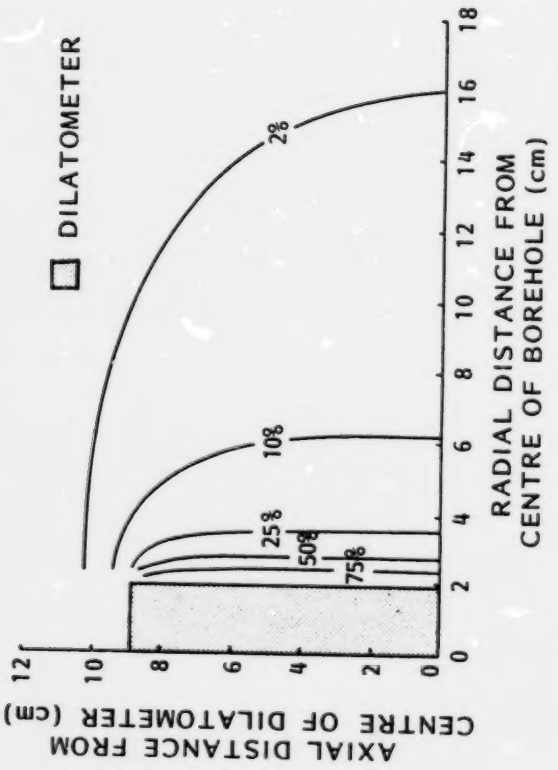
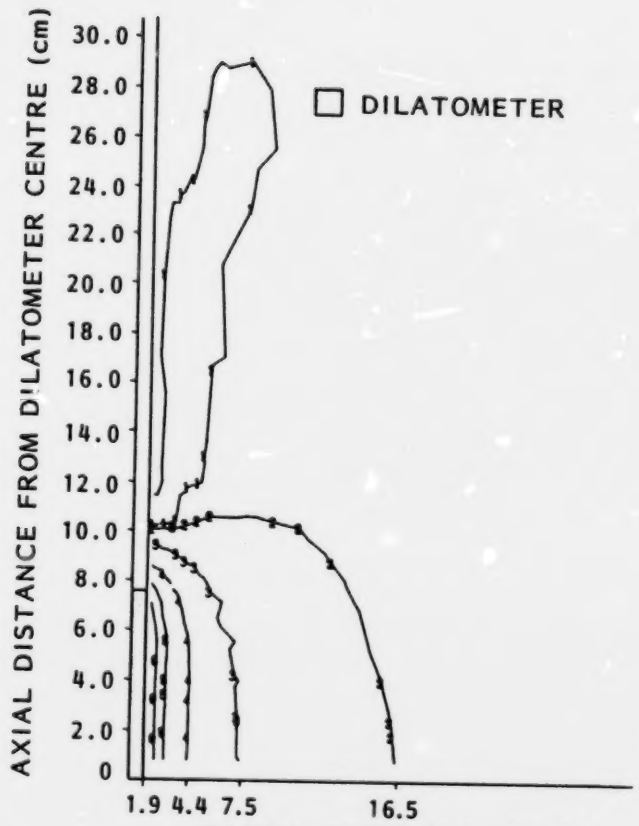


FIGURE 10

UPPER QUADRANT OF PRESSURIZED DILATOMETER
SHOWING STRESS CONTOURS WITH RADIAL DISTANCE
FROM CENTRE OF BOREHOLE IN CONCRETE CYLINDER



Contour 1 - Tensile Zone
Contour 2 - 2% Of Maximum Applied Stress
Contour 3 - 10% Of Maximum Applied Stress
Contour 4 - 25% Of Maximum Applied Stress
Contour 5 - 50% Of Maximum Applied Stress
Contour 6 - 75% Of Maximum Applied Stress

FIGURE 11

UPPER QUADRANT OF PRESSURIZED DILATOMETER SHOWING STRESS CONTOURS WITH RADIAL DISTANCE FROM CENTRE OF BOREHOLE IN FINITE ELEMENT ANALYSIS OF INFLUENCE ZONE

TABLE 1

DEFORMATION MODULUS WITH INCREASING STRESS FOR ROCK BLOCKS

APPLIED STRESS (MPa)			DEFORMATION MODULUS (GPa)		
Vert.	Horiz.	Horiz.	Granite	Sandstone	Limestone
2.8	0.69	0.69	39.19	3.07	7.53
2.8	1.38	1.38	40.52	3.29	10.1
2.8	2.07	2.07	41.98	3.78	12.37
2.8	2.76	2.76	45.4	3.62	13.96
2.8	3.45	3.45	44.74	3.82	15.05
2.8	4.14	4.14	47.24	3.97	15.63
2.8	4.83	4.83	47.5	4.35	16.98
2.8	5.52	5.52	49.23	4.34	17.86
2.8	6.21	6.21	48.9	4.46	18.23
2.8	6.89	6.89	50.28	4.49	19.19
2.8	7.58	7.58	49.88	4.91	18.14
2.8	8.27	8.27	50.28	5.13	19.2
2.8	8.96	8.96	51.38	5.17	20.64

DISTRIBUTION

Mr. H.N. Isaac	Design and Development, H11G27
Mr. T.J. Carter	Design and Development, H11G27
Dr. S.J. Naqvi	Design and Development, H11D18
Mr. G.R. Simmons	AECL Pinawa
Dr. D. Mills	Director of Research
Dr. T.W. Klym	Civil Research
Dr. A.T. Jakubick	Civil Research
Mr. T.J. Carmichael	Civil Research
Mr. R.W. Hughes	Civil Research
Mr. R. Koopmans (2)	Civil Research

Public Reference Centre
Editorial Section (2)
Office Copies (2)
Extra Copies (3)
Section File, KR258